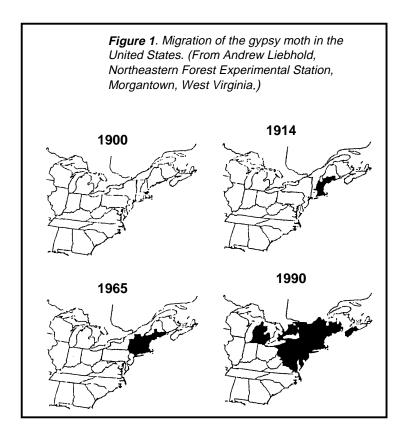
Gypsy Moth Silvicultural Guidelines for Wisconsin

History of the Gypsy Moth

Gypsy moth (Lymantria dispar, L.) is an exotic insect from Europe and was introduced into the United States in the mid-1800s near Boston Massachusetts. The moth spread throughout the Northeast and remained there until the 1930s. The following years saw rapid migration throughout the mid-Atlantic regions (Campbell, 1979). By the 1990s, the moth was found throughout the northeast, mid-Atlantic regions, Michigan, and currently inhabits eastern Wisconsin (Figure 1). The rapid migration west is mainly due to wind and people inadvertently moving the caterpillars and egg masses on recreational vehicles, cars, nursery stock, firewood, and outdoor furniture.



Species Susceptible to the Gypsy Moth

Tree species vary greatly in their food preferences to caterpillars and susceptibility to defoliation (Liebhold et. al., 1995). The most susceptible species are preferred by early and late instar larvae. Some less susceptible species are not preferred by young caterpillars but are preferred by older caterpillars. Some species are not preferred by caterpillars of any age but the caterpillars will feed on them rather than starve. Finally, some species are avoided by gypsy moth caterpillars.

The following tree species are *preferred* by the gypsy moth:

Oaks

Birch (white and gray)

Aspen

Apple

Basswood

Hawthorn

Willow

Witch hazel

Tamarack

Alder

The following tree species are *non-preferred* by the gypsy moth, but can still be defoliated:

Maples

Hemlock

Elms

Spruces

Boxelder

Chestnut

Hickories

Yellow birch

Cherries

Black birch

Cottonwood

Ironwood

Black walnut

Beech

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Decem

Butternut

Juniper

Pines

The following tree species are **avoided** by the gypsy moth:

Ash

Locusts

Balsam fir

Dogwoods

Scotch pine

Mountain maple

Red & white cedar

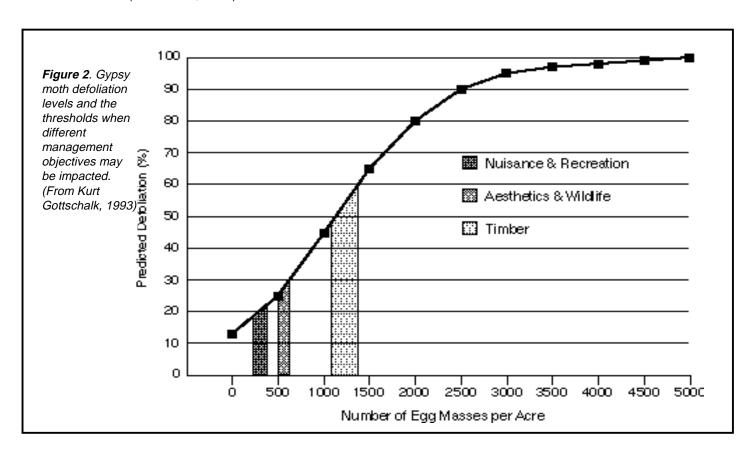
Gypsy Moth Population Behavior

At low population levels (< 100 egg masses per acre), larval instars four through six feed at night and at dawn search for shelter. Shelter is crucial for larval survival because it provides protection from predators. Larvae survive best on oaks that have dead branches and peeling bark and rough, deeply fissured bark. They also find shelter in mature willows, former apple orchards, or any tree with dead branches and rough and peeling bark. Old cars, tires, and other trash in the woods also provide good larval resting habitat.

Gypsy moths remain at low population levels for a number of years because natural enemies prevent the population from increasing. However, in response to favorable weather, the population eventually increases to a point where natural enemies have little effect. At high populations levels (> 500 egg masses per acre) the larvae will feed or search for food both day and night, and shelter becomes less important. The population will eventually crash due to a combination of factors such as starvation and diseases. In Michigan, populations and defiliation remain at peak levels for one year and decline rapidly the following years; whereas, in Northeastern US, two or three consecutive years of defoliation has been common (Campbell, 1972).

Impacts of Gypsy Moth

As gypsy moth populations rise and decline, the resultant impact depends on the conflict with land managers objectives. For example, the manager of a recreational area will accept a lower population level than a manager of timberland. This is because a population high enough to cause light defoliation will interfere with recreational activities but will not threaten the timber values. Populations levels above 1000 egg masses per acre will threaten timber growth (Figure 2) (Gottschalk, 1993).



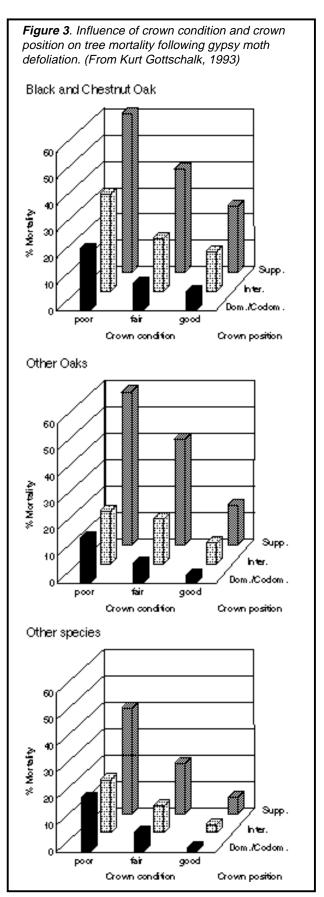
Impacts in the Forest

Gypsy moth defoliates mainly hardwood trees, although it does feed on some conifers. In pure conifer stands, defoliation is minimal; however, in hardwood - conifer mixtures some conifers can be severely defoliated. Most defoliation in Michigan has occurred on the preferred hosts, oak and aspen; the northern hardwood stands in Michigan have not experienced significant defoliation (Witter et. al., 1992).

The heaviest defoliation occurs from late June to early July. The tree will produce a second flush of foliage in mid-summer if twothirds or more of the original foliage is lost. If the tree is defoliated before peak photosynthesis occurs, it must rely on remaining food reserves to produce the second flush of foliage. The additional stress placed on the tree when producing the second flush of foliage can lead to mortality of buds, twigs, and/or branches (Witter et. al. 1992). The timing of defoliation may be extremely important. A mid-season defoliation can be much more damaging to the tree than a spring defoliation because the second flush of foliage does not have time to replenish the food reserves and the new buds do not have time to harden before the colder temperatures arrive (Gottschalk, 1993).

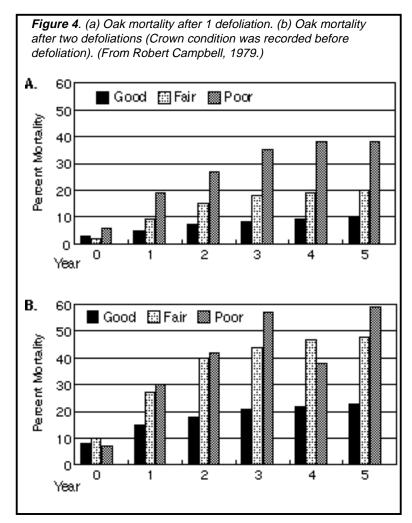
Trees can survive heavy gypsy moth defoliation if they have the proper crown condition and crown class. Trees with crowns in good condition (< 25% dead branches) have the lowest mortality rates after a gypsy moth defoliation. In contrast, trees with poor crowns, (> 50% dead branches), suffer the greatest mortality. Dominant or codominant crown class trees with good crowns can withstand a gypsy moth attack better than intermediate or suppressed crown class trees. However, a dominant tree with a poor crown usually will die before an intermediate tree with a good crown (Gottschalk, 1993) (Figure 3). Most healthy trees can withstand one to two years of defoliation (Figure 4 a and b).

Heavy gypsy moth defoliation can predispose the tree to attack by secondary organisms such as two-lined chestnut borer and shoestring root rot. Two-lined chestnut borer attacks the phloem and cambium layers, while shoestring root rot attacks the



roots. Healthy trees can tolerate or resist attacks by secondary organisms, while trees that are in poor health are at a higher risk. Both organisms often attack a defoliated tree and either can kill the tree (Gottschalk, 1993).

Site characteristics, such as landform, slope, and soil, also play a role in determining gypsy moth population and defoliation levels. Ridge tops, steep, south and west facing slopes and dry, sandy outwash plains are sites favored by gypsy moth. These sites can support high populations of gypsy moth due to the large number of preferred species and habitat. Trees growing on these sites are often crooked, low in vigor, and with deep fissures in the bark, all of which provide prime gypsy moth habitat. These preferred sites also increase the chance for outbreaks and larval dispersal to nearby stands.



In contrast, lower slopes and those with northerly and easterly aspects experience minimal mortality during outbreaks as long as the preferred species are healthy and vigorous. These sites are characterized by straight, fast growing trees with smooth bark, healthy crowns, deep and fertile soils, and little drought stress all of which increase the resistance to gypsy moth damage (Gottschalk, 1993). Gypsy moth populations on these sites are less likely to increase to outbreak levels. However, on these high quality sites, under rare circumstances, defoliation and mortality rates can be high if preventive measures are not implemented.

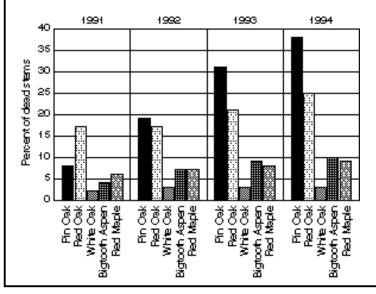
Gypsy moth is only one of many influences on forest health. Tree mortality in Michigan following 10 years of gypsy moth defoliation has been relatively low and has been influenced, additionally by drought and late spring frost (Witter, 1996)(Figure 5). Forests as a whole in the northeast have experienced only minor to moderate tree mortality. The two species that have experienced the greatest mortality in Michigan are white oak on wet and lowland sites and northern pin oak on dry infertile sites (Witter et. al., 1992).

Regeneration of gypsy moth preferred species may decrease because of lower seed production, reduced stump sprouting potential, and mortality of advanced regeneration. Oak regeneration in Michigan that may be at risk to gypsy moth defoliation may need to be sprayed to protect it from defoliation (Witter et. al., 1992). Hicks et. al. (1993) found oak regeneration in West Virginia is just as susceptible to gypsy moth defoliation in clearcuts as in the surrounding forests.

Impact on Forest Succession

The history of forest succession in the presence of gypsy moth has been close to normal except that it has been somewhat accelerated. The trend for future stands may be a shift from the preferred gypsy moth species to non-preferred species. For example, oaks which are early to midsuccessional species may be replaced by later successional species such as sugar maple, at a faster rate than would normally be expected (Witter et. al., 1992). In the future, the relationship between the gypsy moth and the forest may stabilize because of

Figure 5. Tree mortality during gypsy moth outbreak in Michigan (the dead stems are attributed to several factors, once of which includes gypsy moth). (From John A. Witter, 1996.)



an increase in the number of non-preferred species and the natural selection of preferred species that can withstand an attack by the gypsy moth. These changes may lead to forests where outbreaks occur less frequently, are shorter, and cause less mortality (Gottschalk, 1993).

Impact on Wildlife

Gypsy moth defoliation and subsequent tree mortality have two contrasting effects on wildlife species. First, defoliation of the overstory increases the growth of shrubs, grasses, and herbs, which provides some species with additional cover and forage. Many wildlife species also use the trees that die from gypsy moth defoliation as dens. Second, defoliation can reduce the amount of food available to some wildlife species; for example, oaks will produce fewer acorns after defoliation. Defoliation allows increased sunlight penetration and increased forest temperature. Some bird eggs are very sensitive to these increases which may lead to an increase in egg mortality. Eggs may also be more susceptible to predation due to a more open canopy (Witter et. al. 1992).

Impact on Water Resources

Gypsy moth defoliation during high population levels can increase water yield and lower water quality. The increase in water yield is due to less evapotranspiration by the vegetation, while the reduction in water quality is from a higher amount of nutrients in streams due to frass and leaf particles. The loss of cover from defoliation can cause stream temperatures to increase, which can be detrimental to some fish species (Witter et. al. 1992).

Expected Impact in Wisconsin

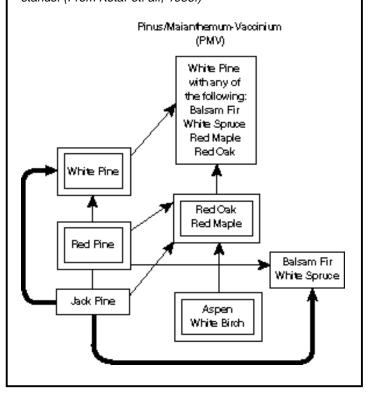
Because Wisconsin has no history of gypsy moth defoliation, we must base our predictions on the experience in the Eastern U.S. and, in particular, Michigan. The northern Lower Peninsula of Michigan has a history of gypsy moth defoliation and, we believe, populations should behave similarly in Northeastern Wisconsin. However, in southwestern Wisconsin which has a generally drier climate, populations may not behave similarly.

- During outbreaks, peak defoliation will occur for only one year in any one location.
- During outbreaks, oak and aspen will experience the bulk of the defoliation and will undergo light to severe defoliation.
- 3. Oak will suffer the bulk of the mortality. Overmature or overstocked, unmanaged oak stands will suffer heavy mortality following defoliation. Oak mortality will be less than 10 % in well managed stands. Oak mortality will generally be scattered but pockets of heavy mortality will occur on in low quality oak on the poorest sites. Aspen on wet or very poor sites and overmature aspen may suffer significant mortality.
- If an outbreak should coincide with drought, mortality will be generally more severe and could include maple and other hardwoods.
- The climate in extreme northern
 Wisconsin is severe enough to limit
 gypsy moth population growth. It is
 unlikely that the area will experience
 severe gypsy moth defoliation.
- Southern Wisconsin woodlots are often isolated by agricultural land. This isolation often reduces gypsy moth populations during the early larval dispersal stage when ballooning larvae fall onto agricultural land rather than

woodland and are unable to find suitable food. This isolation will lead to a wide variation in gypsy moth defoliation levels so that one woodlot may be severely defoliated while another nearby woodlot may have little or no defoliation.

- 7. In the **Central Sands**, the large proportion of preferred species, especially scrub oak, that are low in vigor, crooked, and have deep bark fissures as well as favorable site characteristics (dry, sandy, outwash) will provide an abundant supply of food and favorable habitat to the gypsy moth. These factors are expected to lead to heavy gypsy moth defoliation in this region as well as allowing its population to increase and disperse to other regions.
- 8. In the **Driftless Area** the abundance of preferred species that are crooked, low in vigor, and with deep fissures in the bark as well as favorable site characteristics (ridge tops with shallow to bedrock soils, steep south and west facing slopes) will provide abundant food

Figure 6. Successional pathway of Pinus/Maianthemum-Vaccinium (PMV) habitat type. Successional proceeds from the early stage (bottom) toward the late successional stage (top). Thick lines represent more rapid change. The likely impact gypsy moth may have on this habitat type would be an elimination or reduction in the red oak component form future stands. (From Kotar et. al., 1988.)



and habitat to the gypsy moth. These factors are expected to promote heavy gypsy moth defoliation in this region. These factors will also allow population on south and west facing slopes to increase and disperse to higher quality sites (lower north and east facing slopes) in the region.

Using Wisconsin's Habitat Types to Predict Impact

The habitat typing system developed by Kotar et. al. (1988) and Kotar and Burger (1996) is a powerful tool that can be used to help predict gypsy moth damage in Wisconsin. Gypsy moth damage is expected to vary substantially among similar forest cover types on different forest habitat types.

From a gypsy moth susceptibility standpoint, poor sites include the dry to dry mesic nutrient-poor types (see Table 1). These are prime sites for defoliation and mortality due to the large number of preferred species and habitat (see Table 2). It is expected that these sites will experience the heaviest amounts of damage and silvicultural techniques will generally not be economically feasible. However, preliminary results suggest that intermediate thinnings and selection harvests in poor quality oak stands may improve tree vigor and substantially increase tree survival following defoliation.

The medium quality sites (Table 1), typically dry mesic, nutrient medium to rich, offer the greatest potential for silvicultural techniques to reduce gypsy moth impact.

On good sites (Table 1), typically wet mesic to mesic nutrient rich, gypsy moth defoliation and subsequent tree mortality are expected to be minimal; silvicultural methods can be used but are not generally considered essential.

The successional trends of Wisconsin's forest may be altered by gypsy moth defoliation. On poor sites, repeated defoliations of oak and aspen may cause the successional process to revert back to the early successional stages of a red pine and jack pine cover type. On medium and rich sites, repeated defoliations of oak and aspen should accelerate the successional process (Figure 6).

Table 1
Wisconsin Habitat Types

Site Classification	Soil Moisture & Nutrient Status	Habitat Types of Northern Wisconsin	Habitat Types of Southern Wisconsin
Good to Excellent	Wet mesic to Mesic Nutrient- Medium to Rich	AH, AH-I, AH-Ci, ACaCi, ACaCi-I ACaCi-H, AViO, AViO-I, AViO-C, ATM, ATM- As, AFSt, AAr, ATFD, ATD, ATD-I, ATDH, AFAI, AFAd, AHVib, ArC, TMC,	ATiCa-La, ATiCa-De, ATiH, ATiAs(De), ATiCr(O), ATiCr(As), ATiFrCa, ATiFrCa(O), ATiFrVb, ATiCA, ATiSa, ATiDe, AFAs, AFAs-O, AFASHa, AFTD, AFrDe(O), ATiFrVb(Cr), ATiDe(Pr), ArDe, AFrDe(Vb), AFrDe-Aa, ATiFrCi
Medium	Dry Mesic to Mesic Nutrient-Medium to Rich	AA*, AQVib, AQVib-V, AQVib-Ha, AVDe*, AVVib*, FArAa, AC*, AC-V*, AFTPo, AVib, AFVib	ArCi-Ph, AArVb, ArCi, ArDe-V, AQVb-Gr, ArDe
Poor	Dry to Dry Mesic Nutrient-Poor	AQV*, AQV-s*, QGCe*, QAE*, PMV*, PMV-P*, PMV- Q, PMV-V, QAp*, PAm, PAm- A*, QA*, AQT*, QV, PVRh, PVHa,	PVCr, PVHa, PVGy, PEu, PVG, PVRh

^{*} Indicates Habitat Types which are probably not susceptible to gypsy moth defoliation due to climatic constraints.

Table 2 Common Forest Tree Species

Site Classification	Soil Moisture & Nutrient Status	Northern Wisconsin	Southern Wisconsin
Good to Excellent	Wet Mesic to Mesic Nutrient- Rich	Red Oak, Aspen, Basswood, Sugar Maple, Bitternut Hickory, Yellow Birch, Hemlock, White Pine, Ash, American Beech	Red Oak, White Oak, Big Tooth Aspen, Basswood, Red Maple, Sugar Maple, Bitternut Hickory, Shagbark Hickory, Elm Black Cherry, Ironwood, Yellow Birch, Hemlock, White Ash, American Beech
Medium	Mesic to Dry Mesic Nutrient- Medium	Red Oak, Pin Oak, White Oak, Aspen, Basswood, White Birch, Red Maple, Sugar Maple, Black Cherry, Yellow Birch, Hemlock, White Pine, Red Pine, Jack Pine, White Spruce, Ash, Balsam Fir	Red Oak, Black Oak, Pin Oak, White Oak, Red Maple, White Pine
Poor	Dry Nutrient-Poor	Red Oak, White Oak, White Birch, Aspen, Red Maple, White Pine, Red Pine, Jack Pine, White Spruce, Black Spruce, Balsam Fir	Black Oak, Pin Oak, White Oak, Red Maple, White Pine, Red Pine Jack Pine

Forest Management to Reduce Gypsy Moth Impact

Management Strategies in Wisconsin

There are three primary management strategies available to manage a forest stand with gypsy moth in mind. They are: (1) no active forest management; (2) insecticide application; and (3) silvicultural manipulation.

Implementing no active forest management allows the natural selection process and the resilience of the forest stand to determine the outcome of gypsy moth infestations.

Insecticides may be applied in areas of high recreational use and occasionally in stands that have a large proportion of high value timber. Bacillus thuringiensis (B.t.), Dimilin, and GYPCHEK are the three most commonly applied insecticides. B.t., a bacterial insecticide, kills the larvae of gypsy moth and other moths and butterflies when it is ingested. Dimilin, a growth regulator, interferes with the molting process of the larvae. B.t. and Dimilin are applied early in the life cycle of the caterpillar, late May to early June (Katovich and Haack, 1991). GYPCHEK, a commercial formulation of a naturally occurring virus, is selective only to the gypsy moth larvae. GYPCHEK has no effect on non target organisms and should be applied during larval instars one or two (Reardon and Podgwaite, 1992).

Silvicultural Options

Land managers can apply silvicultural methods to decrease the likelihood and severity of defoliation and to improve the vigor of forest stands thereby increasing tree survival following gypsy moth defoliation. Harvests and intermediate thinnings can be applied to reduce food quality and shelter for gypsy moth larvae and pupae. Intermediate thinnings, such as crop tree release, improve crown condition and vigor of the residual trees in the stand. The released trees will grow larger, more vigorous crowns that are more likely to survive defoliation. The addition of the habitat type information greatly increases the predictability of the outcomes of silvicultural practices.

The following silvicultural options are generalized; they are not meant to be all-inclusive. Land managers should select those options that are consistent with management objectives to develop a general approach to managing individual stands.

On all sites

- In oak stands, increase the proportion and vigor of non-preferred species, such as maples, hickories, black cherry, and ash
- 2. Encourage regeneration of non-preferred species.
- Remove gypsy moth preferred species that are small and poor quality or girdle these trees to create wildlife snags. If girdling is used, make sure the crown and bole are not touching surrounding live trees.
- Remove trees that could create a habitat for the gypsy moth such as trees with a large number of dead branches and rough and peeling bark.

On poor sites

- Attempt to convert the stand to nonpreferred species during the harvesting process.
- Convert to conifer or non-forest cover type.
- 3. Where there is strong management incentive to maintain an oak cover type on a poor quality site:
 - a) Intermediate thinnings, such as crop tree release, can improve the crowns and vigor of preferred and non-preferred species and therefore improve their ability to survive defoliation
 - b) Clearcut to encourage oak sprouts with a mixture of non preferred species.

On poor and medium sites

 Maintain < 50% basal area of gypsy moth preferred species.

On medium and rich sites

- Intermediate thinnings, such as crop tree release, can improve the crowns and vigor of preferred and non-preferred species and therefore improve their ability to survive defoliation. Favor dominant and codominant trees with straight stems, smooth bark, and healthy crowns.
- Maintain healthy preferred and nonpreferred species during the harvesting process to help limit gypsy moth population increases.

Timing of Thinning

- Stands that are poor quality, overstocked, and/or contain overmature preferred species: a thinning may be performed two or more years before or after a gypsy moth outbreak to remove the less vigorous trees (Mech, 1996).
- Stands that are healthy, vigorous, and/or fully stocked: a thinning may be performed one year before or after a gypsy moth outbreak to enhance the vigor of the residual stand (Mech, 1996).

Regeneration Considerations

- Regeneration of oak and other preferred species will have the highest defoliation and mortality rates during outbreaks. It may need protection with insecticides.
- Stump sprouts of gypsy moth preferred species should be thinned to one stem per stump, in order to improve vigor and resistance.
- Gypsy moth usually has little impact on pine regeneration in pure pine stands, while in hardwood - pine mixtures the impact on pine regeneration could be severe.
- When establishing new oak plantations, plant mixtures with conifer and nonpreferred hardwood species on medium and poor habitat types. Plant pure oak only on high quality sites.

Gypsy Moth and Wildlife Management in Wisconsin

A potential conflict exists between forestry and wildlife management goals when attempting to manipulate gypsy moth habitat. Forest managers may wish to increase the percent of non-preferred species to reduce defoliation and mortality on sites that provide

habitat for gypsy moth, while wildlife managers may wish to maintain or increase the oak component for greater mast production.

The poor sites that support the highest gypsy moth populations are ridge tops, steep, south and west facing slopes and dry, sandy outwash plains. These sites are also favored by wildlife for their milder microclimate, reliable food source, and cover. During the winter months, south and west facing slopes do not accumulate as much snow as north and east facing slopes, which allows wildlife the relative ease of foraging in a period when food is scarce. In addition, temperatures on these slopes rarely drop to the -25° F threshold, which is detrimental to the moth's egg mass, thus increasing the proportion of eggs that are able to hatch in the spring. Another feature of the south and west facing slopes is that they are less likely to experience a late spring frost, which can damage newly formed tree buds as well as kill gypsy moth larvae. Finally, the hot and dry microclimate on these slopes during summer months promote larval development and survival.

Trees growing on poor sites on south and west facing slopes are able to provide reliable food source and cover to both wildlife and gypsy moth. Poor growing conditions found on these sites induce trees to produce a greater quantity of seed more frequently than would be typical on other sites. This reliable seed production benefits many wildlife species throughout the year. However, the poor growing conditions and available habitat found on these sites also increases the susceptibility to gypsy moth defoliation and mortality. The wildlife prefer the brushy characteristics found on these slopes for cover, while the gypsy moth prefers the low vigor and crooked trees with deep bark fissures for its cover. These sites can support high populations of gypsy moth due to the large number of preferred species and habitat. They also encourage gypsy moth outbreaks and widespread dispersal to other stands. The Driftless area and central sands of Wisconsin are expected to support rapid gypsy moth population increases that will cause heavy defoliation and dispersal.

Silvicultural Options for Wildlife Management in Southern Wisconsin

- Preferred species on ridge tops, steep south and west facing slopes, or sandy outwash plains can continue to be favored if silvicultural measures are implemented to improve tree condition (Figure 8). If egg masses are present, removing them may help reduce the gypsy moth population and dispersal.
- Reduce the percentage of preferred species and create a savanna appearance in the openings.
- Within high-risk stands, increase the proportion of non-preferred species that will benefit wildlife species and minimize defoliation. These species can include hickory, black walnut, white pine, red cedar, and spruce.
- 4. Create a stratified structure for wildlife forage and cover. For example, on ridge tops, increase the white pine component, on mid slopes increase the non-preferred hardwood and conifer species, and on lower slopes and bottoms increase the non-preferred hardwoods and conifers as well as shrub components.

Landscape Management Considerations

- The fragmentation of southern
 Wisconsin's forests may help manage
 gypsy moth populations because during
 the dispersal stage, the caterpillars are
 unlikely to survive in openings where no
 preferred food is available.
- Where a single habitat type exists over large areas, a diverse arrangement of stands of oak, maple, pine, and other non-preferred species can reduce the likelihood of damage by the gypsy moth as well as other defoliators.
- Take full advantage of the available diversity of habitat types and current cover types across the landscape to reduce short term and long term pest threats.
- Decrease the oak component and increase the conifer component on ridge tops and other susceptible sites in the central sands and Driftless area of Wisconsin.
- 5. Increase percent of non-preferred species over the landscape to decrease the probability of population increases.

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